The Application of Semantic Web Technology in Manufacturing Grid

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Abstract

Concerning the knowledge-intensive environment, the paper introduces Semantic Web(SW) technology to Manufacturing Grid (MGrid). Resources and services in MGrid are described in the well-defined meaning, so that computers can understand resource and service information to interoperate seamlessly. In the paper, a semantic-aware MGrid architecture (SAMGA) based on WS-Resource Framework (WSRF) is first presented, in which the stateless Web Services are semantically described using OWL-S and the stateful resource descriptions are semantically enhanced using OWL. Then a semantic matching algorithm is proposed for SAMGA. Finally, SAMGA has been applied to the magnetic bearing resource and service sharing platform (MBRSSP).

Keywords Manufacturing grid, Semantic Web technology, Semantic matching algorithm, Architecture

1 Introduction

Through the network, manufacturing grid (MGrid)[1] makes all kinds of enterprises and resources geographically distributed connected and form a virtual organization (VO), which is centralized in logic but distributed in physics. In this VO, all resources can be shared and all enterprises can be employed to work collaboratively towards to a common target of dealing with a distributed manufacturing task or problem.

The kernel of MGrid is to share manufacturing resources and use services provided by manufacturing resources pellucidly. However, MGrid resources are far more diverse and complex than those of Grid Computing and there isn't a unified format for describing manufacturing resources and services. There exist lack of relationships and semantics. Moreover, manufacturing service composition is notoriously complex and challenging. These problems seriously hinder the development and application of MGrid. Even though Web Services Description Language (WSDL) was used extensively in Web Service and Grid at present, regrettably, it couldn't address these problems due to lack of semantic parts. Tangmuarunkit argued that existing resource description and resource selection in the Grid was highly constrained[2].

Due to the complexity of some manufacturing processes, some manufacturing tasks in MGrid should be decomposed into several subtasks, which cannot be further decomposed and can be executed by a single resource service. Extensive studies have been conducted related to web service composition problem in service-oriented system and distributed system. Existing research efforts for web service composition have been undertaken in two orthogonal directions: 1) manual composition, and 2) automated composition. Manual composition is a time-consuming task, and it is supported by major IT enterprises such as IBM and Microsoft. In this approach, the web service developer selects the outsourced web services that are relevant to their composition intents and programs the interaction logic of the component services with a low level programming language such as BPEL[3]. For the automated composition, the information must be understandable by computers, so that they can perform more of the tedious work involved in finding, sharing, and finally combining information in MGrid. The mutual understanding between computers is also important for the optimal composition of MGrid resources.

The appearance of SW[4] brings a new hope of solving the above issues. SW is an evolving extension of the World Wide Web in which the semantics of information and services on the web is defined, making it possible for the web to understand and satisfy the requests of people and machines to use the web content. Many researches have applied SW technologies to grid. All resources and services in grid are adequately described in the well-defined meaning that is machine-processable, which is favor of enabling computers and people to work in cooperation. In the grid system, “semantics” plays an important role in the following aspects:

- More effectively discovering and managing dynamic resources in virtual organizations, such as the description and processing of semantic service, resource classification, event notification, origin tracking. The problem of heterogeneity of information in the distributed environment would be resolved at the bottom of the grid architecture;
- Linking and cooperating with the information stored and available within a grid automatically, so that it can support the knowledge-intensive applications at the top of the architecture.

The rest of the paper is organized as follows. In section 2, some related work is summarized. In section 3, SAMGA is presented. Section 4 introduces a semantic matching algorithm which is especially designed for SAMGA. Section 5 provides the resource and service of magnetic bearing resource and service sharing platform based on SAMGA. The conclusion is given in section 6.

2 Related Work

Early in 2001, a number of researchers were increasingly conscious of the necessity of combination of Semantic Web and Grid. This was firstly captured by David De Roure in the UK e-Science program[5]. Global Grid Forum (GGF) also established Semantic Grid Research Group (SEM-GRG) to realize the added value of emerging Web technologies and approaches, in particular Semantic Web and Web 2.0, for Grid users and developers. There are some representative research and projects abroad, such as myGrid, CombeChem, GEODISE etc; in China, there is the National Grand Fundamental Research 973 Program: study on basic theory, model and method of Semantic Grid, which would mainly resolve three issues: standard resource organization, semantic interconnection and intelligent aggregation[6].

Above researches are mostly applied in the environment of Computing Grid or Data Grid. There are few researches of Semantic Web technology for manufacturing. For instance, Yang et al. presented a Semantic Web Services approach for automated integration of manufacturing systems and services[7]. Lemaignan et al. presented a proposal for a manufacturing upper ontology in order to draft a common semantic net in manufacturing domain, and applied the ontology in the automatic cost estimation and semantic-aware multi-agent system for manufacturing[8]. He et al. proposed an ontology-based manufacturing resource discovery architecture, and gave the discovery algorithm of manufacturing resources based on semantic extending and QoS[9]. Li et al. used ontology to describe resources and services in manufacturing grid, and extend UDDI to support service publishing and retrieval[10].

It has been realized that SW have an extremely broad development prospect, but the application in manufacturing just begin, especially in MGrid. Most researches have focused on the description of resource and service of MGrid, not on the semantic-enabled MGrid architecture and semantic matching algorithm. Therefore, this paper proposes a new semantic-aware architecture and a semantic matching algorithm for MGrid.

3 Semantic-aware MGrid Architecture

Based on concepts and technologies of WSRF and SW, the semantic-aware MGrid architecture (SAMGA) is designed as shown in Fig.1. For the purpose of the pellucid interoperation, SW technology should be applied upon grid middleware. It is important to note that the "semantics" permeates the full vertical extent of architecture and is not just a semantic (or knowledge) layer on top: it is semantics in, on and for the Grid. The function of every layer as follows:

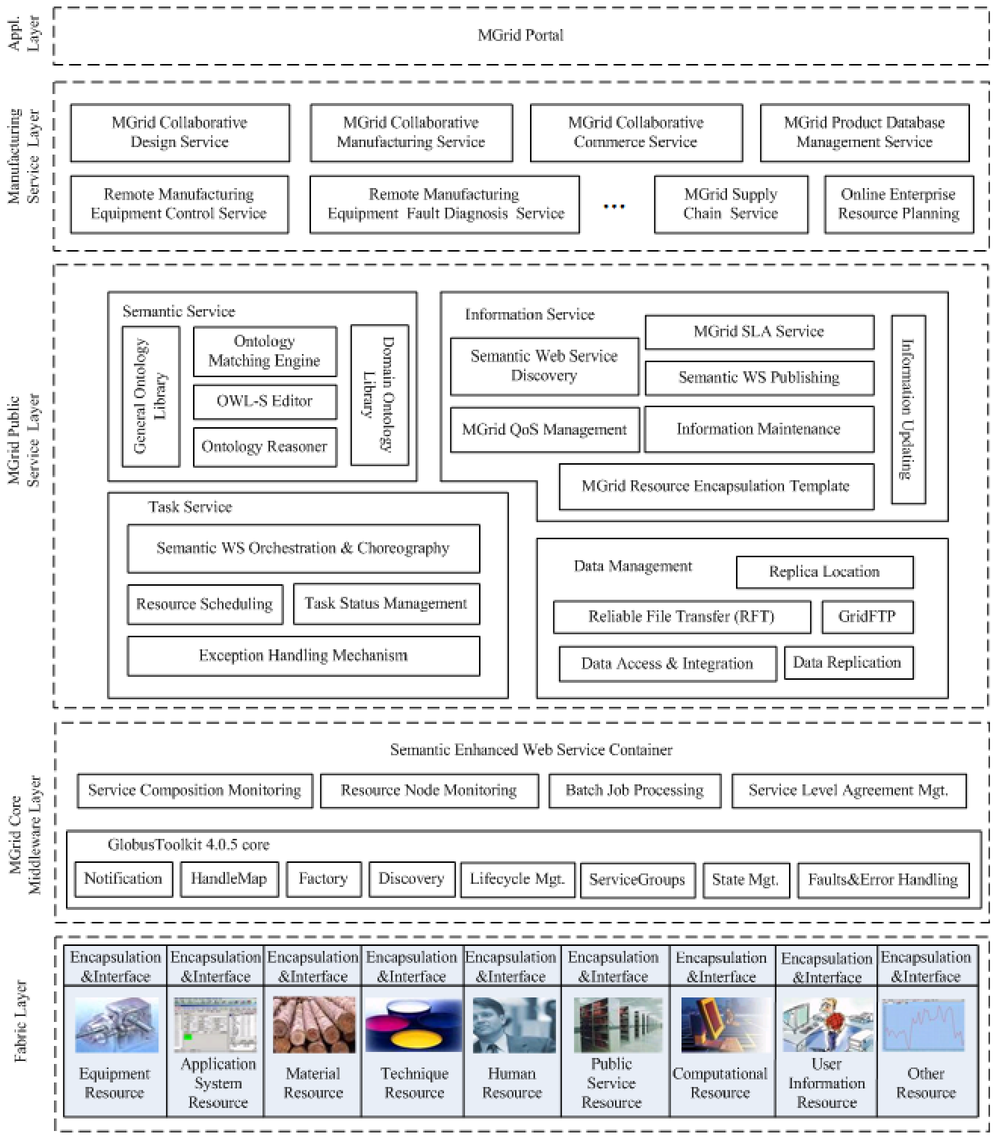

Fig.1 The semaritic-aware MGrid architecture

(1) Fabric Layer: Its basic function is that local resources would be encapsulated into global resources which could be shared for the MGrid application layer. At the endpoint of physical resources node, the interfaces of lifetime management, state management and notification would be provided; Web Services standardize various functional operations provided by resources node and offer the standard

interfaces of access services. Web Services would be described by using service upper ontology OWL-S and manufacturing domain ontologies which are written in standard ontology language OWL. A flexible and high-quality "WS-Resource" would be constructed by combining standard Web Services with dynamic manufacturing resources. WS-Resource is the extended grid service according with WSRF specification, hiding the heterogeneity of manufacturing resources and being rich in "semantics".

(2) MGrid core middleware layer: MGrid core middleware is essentially a semantic enhanced Web Service container, because the SW standards provide the Web Service container with the capabilities of processing semantic information, such as services composition monitoring, batch job processing and service level agreement (SLA) management. It is the basic running environment of grid service, which will be deployed in each grid node in advance. It is recommended that MGrid core middleware is developed on Globus Toolkit 4.0.5 core.

(3) MGrid public service layer: This is a service set which provides the common operations for MGrid applications, including information service, data service, task management and semantic service. The semantic service includes three components:

• To provide the domain ontology library (knowledge workers who are a little familiar with the knowledge of manufacturing can easily use protg[11] to establish and maintain ontology library) and the general ontology library (e.g., WordNet [12], Cyc[13], Sumo[14]);

• To provide the API of ontology libraries (e.g., Jena framework is open source and grown out of work with the HP Labs Semantic Web Programme, which provides an OWL API and SPARQL query engine[15]);

• To provide the ontology reasoner (e.g., Racer[16], Pellet[17], FaCT++[18]), OWL-S based matching engine[19] and OWL & OWL-S editor[20].

(4) Manufacturing service layer: On the basis of the MGrid public service layer, the intelligent toolkits for the manufacturing applications are developed, for example, CAPP expert system based on artificial intelligence.

(5) MGrid application layer: in virtue of the domain dependent programming model (e.g. CORBA, COM, JavaBean etc.) and man-machine interaction mechanism, the man-machine interfaces (e.g. visual component Portlet, Servlet, etc.)are provided to MGrid users for MGrid applications. Both OWL-S and the Web Service Modeling Ontology (WSMO) [21] can describe services semantically. OWL-S uses OWL in combination with WSDL. WSMO uses F-Logic to perform inferences with services, and its XML-based format gives external agents access to the service features. The paper adopts OWL-S as MGrid services description language (see Fig. 5).

4 Procedures of MGrid Resource & Service Publication and Discovery Based on SW

4.1 MGrid Resource & Service Publication

Elenius et al. developed an OWL-S plug-in for Protégé as OWL-S editor [20]. The OWL-S editor provides a graphical user interface to create and modify an OWL-S description including all three parts: ServiceProfile, ServiceModel and Service-Grounding. Publishing SW services is more complex than Web Services. However, it can contribute to automated discovery, negotiation, composition, execution, and monitoring of web services. First of all, RSP develop WSDL documents of Web Services. Then with the help of OWL-S editor, RSP fill in ServiceProfile information and use Service–Model to define service executable process. At last, RSP import the above WSDL documents into OWL-S files. In order to describe MGrid services formally as much as possible, RSP can enter some keywords and browse ontolgoies that include the keywords, as well as synonyms, superclass or subclass of these ontologies, when entering IOPEs. information. Thus RSP select the right ontology names as the IOPEs terms.

4.2 MGrid Resource & Service Discover

The procedures of semantic-aware service discovery are shown in Fig.3. RSC just need to enter input and (or) output term(s) via the man-machine interaction interface. In the same way of resource & service publication, after that ontology reasoner performed reasoning and expansion of ontology, RSC select the right ontology names. The selected ontology names and those related terms (e.g., synonyms, superclass or subclass) are sent to MDS4 as keywords. MDS4 connect to all MGIIS and return the Service Profile information to OWL-S based matching engine. Matching engine would extract I/O information from MDS4 and then start to perform the matching algorithm (detailed in section 5) to compare I/O information between returned services and RSC request. Service query interface will show the matching results (including service name and address). Thus RSC connect the selected MGRIS to schedule this service node.

5 Semantic Matching Algorithm

The matching algorithm is the key to the implementation of the SW technology in MGrid. The algorithm is the main process of the OWL-S based matching engine in the core middleware layer.

The principles of the semantic matching algorithm, which are based on the semantic ontology library-WordNet, are as follows:

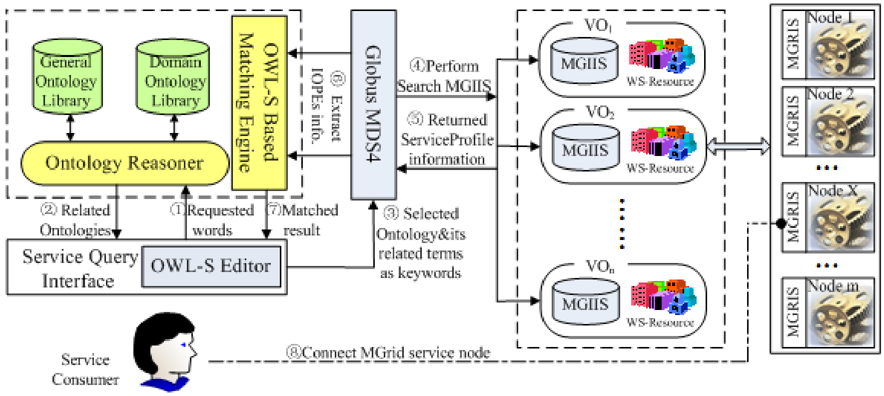

Fig.2 Semaritic-aware MGrid service dicovery model

(1) The smaller the semantic distance, the greater the similarity. The semantic distance between one concept and itself is 0, and their similarity is 1. When the semantic distance between concepts is infinite, their similarity is 0. In the hierarchical structure tree (see Fig.3), the semantic distance refers to the length of the shortest path between two concepts. As shown in Fig.3, the semantic distance of O_{31} to O_{36} is denoted by $L_1 + L_2$, where L_1 refers to the distance of O_{31} to O_{11}, L_2 refers to the distance of O_{36} to O_{11} , and O_{11} is the nearest common concept of O_{31} and O_{36}.

(2)The more the semantic overlap, the greater the similarity. The semantic overlap refers to the level of the same meaning that both concepts involve. As shown in Fig.3, the semantic overlap of O_{31} to O_{36} is denoted by L, where L refers to the distance of O_{11} to O_0, and O_0 is the top concept in the hierarchical structure tree. Generally speaking, the larger the semantic overlap , the smaller the difference between the meanings of both concepts. For example, the similarity between O_{31} to O_{32} is larger than that between O_{11} to O_{12}.

(3) The more detailed the classification, the lower the similarity. There are fine and coarse classifications of concepts in the semantic dictionary. Hence, the concept density isn't a fixed value. There must consider the concept density in the algorithm .

(4) The similarity is asymmetric. Generally speaking, the similarity from O_1 to O_2 is unequal to that from O_2 to O_1. For example, the similarity from "lathe" to "machine tool" is larger than that from "machine tool" to "lathe". Because machine tool includes lathe, grinder, shaper etc. Therefore, we introduce the vector curves, such as the broken blue curves with arrow in the Fig.3.

According to the above principles, the similarity of resource functionality from concept O_1 to concept O_2 is defined Sim($O_1 \to O_2$) as follows:

$$Sim(O_1 \to O_2) = \frac{L}{L + \alpha(O_1, O_2)\frac{L_1}{\rho(o)} + [1 - \alpha(O_1, O_2)]\frac{L_2}{\rho(o)}}$$

where $\alpha(O_1, O_2) = \begin{cases} \frac{L+L_1}{2L+L_1+L_2}, L_1 \le L_2 \\ \frac{L+L_2}{2L+L_1+L_2}, L_1 > L_2 \end{cases}$ is the adjusting parameter of the asymmetry of similarity. The concept density [22] $\rho(o) = \frac{\sum_{i=0}^{m-1} nhyp^{i^{0.20}}}{descendants_0}$,where nhyp refers to the mean number of hyponyms per node, h refers to the height of the subhierarchy, and m refers to the number of senses in the hierarchical structure tree.

There is an example of how to cacluate the similarity in the field of machine tool service. The goal of calculating the similarity is to match two resource names. The resource name stands for the resource functionality. The hierarchial structure tree in the WordNet is shown in Fig.4. From the Fig.4, we can obtain the data in the Table 1.

Table 1 The similarity calculation

$O_1 \to O_2$	L	L_1	L_2	m	$desc-endant_o$	$\alpha(O_1, O_2)$	nhpy	$\rho(O)$	$Sim(O_1 \to O_2)$
lathe→ machine tool	9	2	0	2	5	0.45000	1.15091	0.43018	0.81138
grinder→ machine tool	9	1	0	2	5	0.47368	1.15091	0.43018	0.89099
shaper→ machine tool	9	1	0	2	5	0.47368	1.15091	0.43018	0.89099
machine tool →lathe	9	0	2	2	5	0.45000	1.15091	0.43018	0.77874
machine tool →grinder	9	0	1	2	5	0.47368	1.15091	0.43018	0.88033
machine tool →shaper	9	0	1	2	5	0.47368	1.15091	0.43018	0.88033
lathe→ milling machine	10	1	1	2	5	0.45000	1.00000	0.66667	0.86957
lathe→ grinder	9	2	1	2	5	0.47619	1.15091	0.43018	0.72396

In the table 1, it's easy to see that Sim(lathe → tool) > Sim(lathe → grinder) and Sim(lathe → machine tool)> Sim(machine tool → lathe). The first inequation shows when a lathe is required, the resource node of machine tool is much better for the searching result than that of grinder. The second inequation verifies the asymmetry of similarity. We set a threshold for the similarity in the MGrid sysytem. if Sim($O_1 \rightarrow O_2$) is no less than the value of threshold, we argue that O_1 is similar enough to O_2.

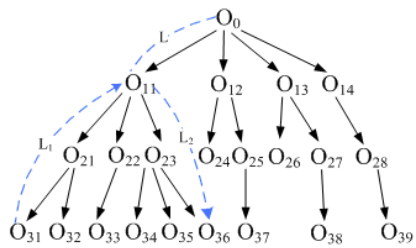

Fig.3 The hierarchical structure tree

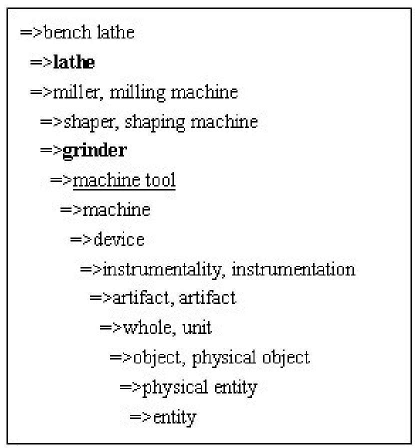

Fig.4 An example of hierarchical structure tree in wordnet

6 Application

A magnetic bearing is a new type of high performance bearing. However, each type of magnetic bearings must be designed and manufactured according to the concrete objects. A large number of resources are needed in the development of magnetic bearing. In order to realize the sharing and collaborative work of all needed resources, according to SAMGA, the magnetic bearing resource and service sharing platform (MBRSSP) is developed. Resource & service providers (RSPs) can publish the own resources through the manufacturing resources publication center, as shown in Fig.4. The publication center provides the semantic template for resource and service publication and automatically generates the semantic documents. Resource & service demanders (RSDs) can search the needed resources at the resource optimal-allocation center as shown in Fig.5; RSDs can also reserve all kinds of resources for MGrid tasks through the co-reservation system, as shown in Fig.6. The semantic matching can provide the better searching result for both the optimal-allocation and the co-reservation.

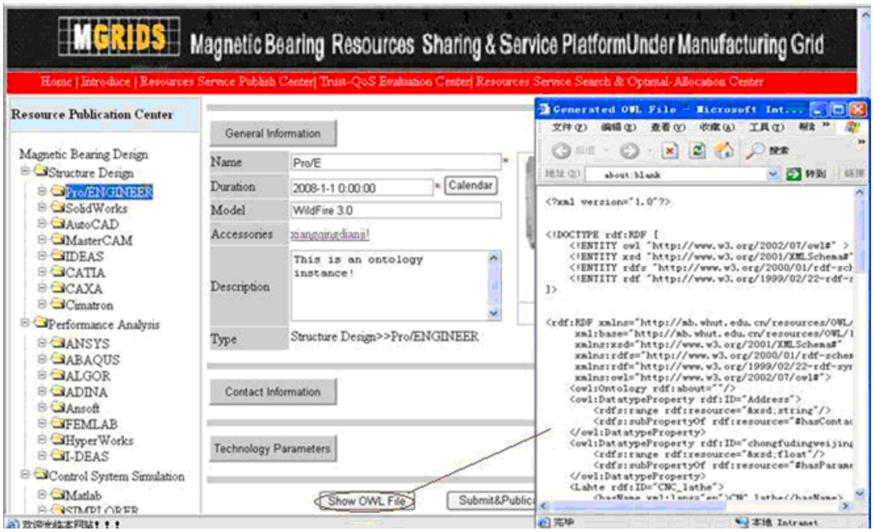

Fig.5 Manufacturing resource & servicepublication center based on OWL&OWL-S

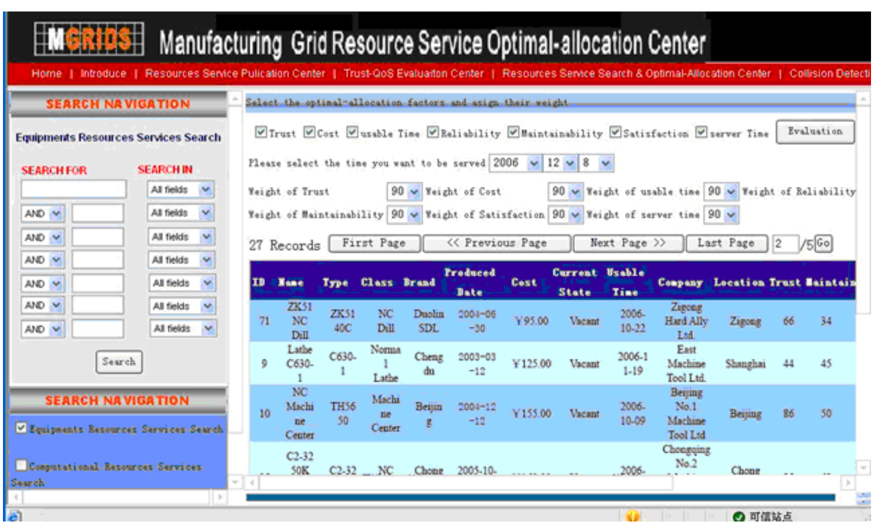

Fig.6 MGrid resource & service optimal-allocation center

7 Conclusion

This paper presented a semantic-aware MGrid architecture that exploits Semantic Web technologies to solve manufacturing problems. The semantic environment at the bottom of SAMGA can adequately support the knowledge-intensive application of MGrid on the top layer. With the support of SAMGA, a new information model suitable for the semantic and grid environment is designed, which can realize the fuzzy matching. Furthermore, the information model is also called the pull model, which avoids a large number of redundant information.

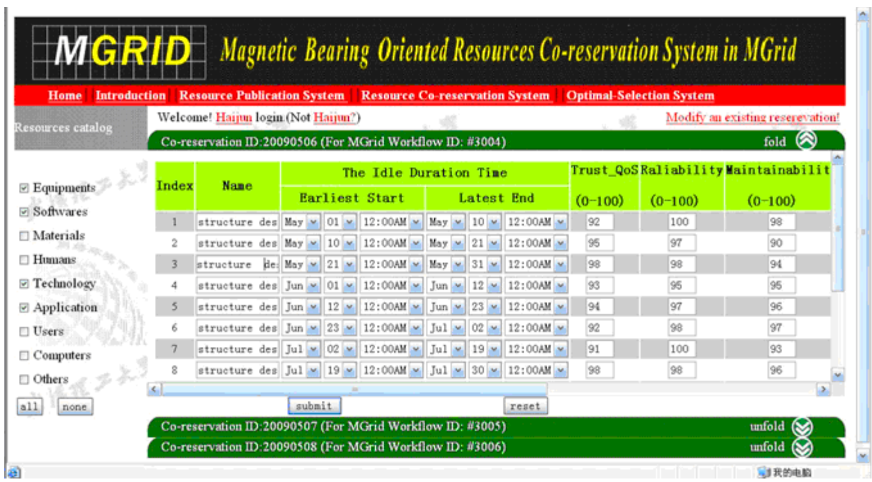

Fig.7 MGrid resource & service co-reservation system

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